Vehicle Power Line Channel Modelling under CST Microwave Studio

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Abstract—**For every car manufacturer, it is essential to reduce the weight of vehicles. To help manufacturers reduce weight factors, cable industries propose several solutions to reduce the weight of harnesses such as creating new wires with reduced conducting sections. However, we offer another complementary solution, based on using the PLC (Power Line Communication) technology inside a vehicle. In this article, we address the problem of vehicle PLC, focusing on the channel modelling. The aim of this paper is to design a novel PLC channel model under CST MWS (CST Microwave Studio) software, able to emulate a real vehicle PLC environment. Simulation results are compared to experimental measurements.**

Keywords- Power Line Communication; Vehicle Power Line Channel; Channel Modelling; 3D Model

I. INTRODUCTION

Vehicle manufactures continue to increase the electrical and electronic devices in vehicles. This growing trend comes from the demand for electronic control and command equipment. All those equipments offer to the driver comfort and safety. Many techniques are being developed: anti-collision radar, reversing radar, white line crossing detection, space measuring system, indication of a vehicle at a blind angle, adjusted the speed according to the space behind the vehicle in front, and triggers the brakes in an emergency etc. With increased numbers of equipment, the weight of vehicles has been increasing (20 kg per year in Europe). But in the same time, Euro 6 standards [1] require a reduction pollutant emission (80 mg/km). The weight of the car is related directly to 75% of fuel consumption. This means that reducing the weight of a vehicle by 100 kg is equivalent to reducing the fuel economy by 11 g of CO2 per kilometre. That is why manufacturers have set themselves the goal of quickly reducing the weight of the vehicle by 200 kg by the year 2020.

All these onboard systems mean an increase in the number of wires and cables in the vehicle. In this context, our solution is based by using the PLC technology. The PLC technology is a communication method that uses electrical wiring to simultaneously carry both data and electric power.

The aim of this paper is to design a vehicle PLC channel model under CST MWS software [2], which could be reliable in analyzing broadband vehicle PLC systems. This modelling study will be validated by experimental measurements.

The paper is organized as follows. In Sections II, we describe the vehicle PLC channel model under CST MW Studio. In Section III, we provide the simulation results and we compare it with experimental results. Finally, the conclusions follow in Section IV.

II. VEHICLE CHANNEL MODELLING

The frequency response of the current vehicle network electrical is not flat but has resonances and fading, due to echoes and reflections between the transmitter and the receiver [3].

There are many reasons behind these changes for example, the coupling between the different wires of the strand, the wiring ohmic losses and the multipath characteristics of the channel.

Also, the increasing number of interconnections in the car is inevitable despite the use of multiplexing. It causes disadvantages in conception and fabrication that makes the fault diagnosis and detection very difficult. This implies that the classic electric network of the vehicle is currently reaching their technological limits. It is therefore necessary to design a new on-board electrical network of a vehicle by designing a new cabling architecture.

Our idea is to reduce the number of wires to two conductors plus the ground. That is means; the channel transmission is composed of two cables, the first cable carrying the power to supply the electronic and electrical components, and the second cable for data transmission as show in Fig. 1.

In Fig. 1 the battery is replaced by the Randles battery model [4] as show in Fig. 2.

Fig. 3 shows the cable used in the experimental measurements. The cable is a multi-core, round twin cable constructed from two cores of thin wall cable with a PVC (Poly Vinyl Chloride) outer sheath. It is suitable for low voltage car. Thin wall cable is the most used as standard by car manufacturers due to its high-performance characteristics. The cable specifications are listed in Table I.

The Fig. 4 shows a section of a vehicle electrical network with four outlets, E, S, P1 and P2. This section is used in measurements to determine the S-parameters between E

(input) and S (output) in the band [500 KHz – 70 MHz]. The modelling of the vehicle PLC channel (Fig. 4) by using the MLT approach (Multiconductor Transmission Line) under Matlab software and by using scattering matrix [S] under ADS software (Advanced Design System) was validated and published in [5][6].

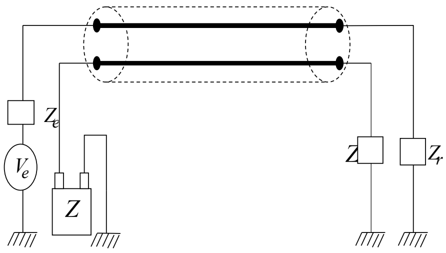

Fig. 1. Transmission channel with two conductors

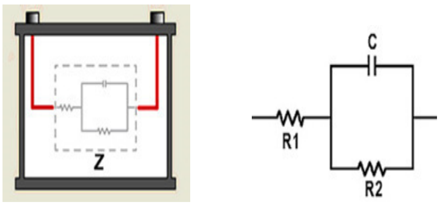

Fig. 2. Randles battery model

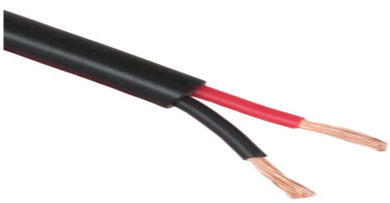

Fig. 3. Cable used in measurements

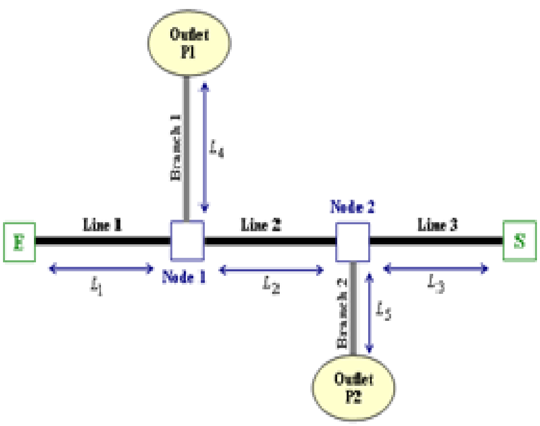

Fig. 4. Section of a vehicle electrical network

TABLE I. SPECIFICATIONS CABLE USED IN THE MEASUREMENTS

Parameter	Specification
Cores manufactured	*ISO 6722-1:2011(Class B)*
Voltage rating	*12 V & 24 V*
Nominal current rating	*2x25 A*
No./size of conductors	*2x28 /0.30 mm*
Conductor cross section	*2x2.0 mm²*
Overall cable diameter	*7.8 mm*
Conductor material	*Plain copper*
Core insulation material	*PVC (hard grade)*
Sheath insulation material	*PVC*
Working temperature	*-15 to +70°C*

In this paper, we are interested in modelling the vehicle PLC channel in 3D simulation under CST MWS by using FIT method (Finite Integration Technique).

The FIT was first proposed in 1977 by Thomas Weiland [7]. The FIT is a discretization scheme for Maxwell's equations in their integral form suitable for computers and it allows to simulate real-world electromagnetic field problems with complex geometries [8]. In [8], Algebraic properties of the discrete formulation make it possible to develop long-term stable numerical time integration. And, the FIT is a generalization of the FDTD method (Finite Difference Time Domain) [9].

Also, CST MWS software is based on FIT method. The power cable structure is built in 3D after the definition of calculation volume. 3D simulation can take into consideration all the electromagnetic phenomena resulting of the propagation of broadband signals in power cable. The structure is excited by a waveguide port. Fig. 5 shows the 3D structure of the Cable by using CST MWS, respecting the same specifications of the cable used in the measurements (Table I).

The frequency response of an electric cable depends on the geometrical parameters: conductor cross section, overall cable diameter, distance between conductors, number of conductors, thickness of insulators, shape and length of the cable. It also depends on the technological parameters: relative permittivity of the insulators, loss angle of the insulators and electrical conductivity of the conductors. The parameters are presented in Table II. Also, it should be noted that the parameters (relative permittivity and loss angle of the insulators) are unknown when designing the cable. Their values were determined by using 3D simulation in order to get as close as possible to the measurement.

Fig. 6 shows the vehicle electrical network segment modelled under CST MWS. It corresponds to the vehicle electrical network segment used in the measurements (Fig. 4). The battery is represented by its equivalent impedance described by the Randles battery model.

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TABLE II. GEOMETRIC AND TECHNOLOGICAL PARAMETERS OF THE CABLE

Dimension	Value
A	3.9 (mm)
B	1.5 (mm)
D	4 (mm)
R	0.79 (mm)
S	2 (mm²)
e_{int}	1 (mm)
σ	58.6 1E6 (S/M)
$tan(\delta_{int})$	0.01
$tan(\delta_{ext})$	0.03
ε_{int}	2.4
ε_{ext}	3.1

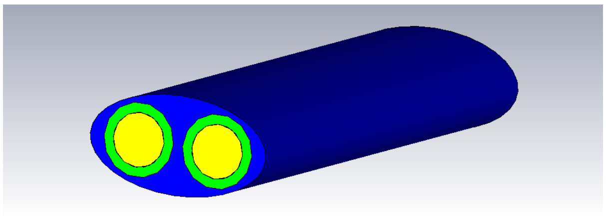

Fig. 5. 3D structure of Power Cable

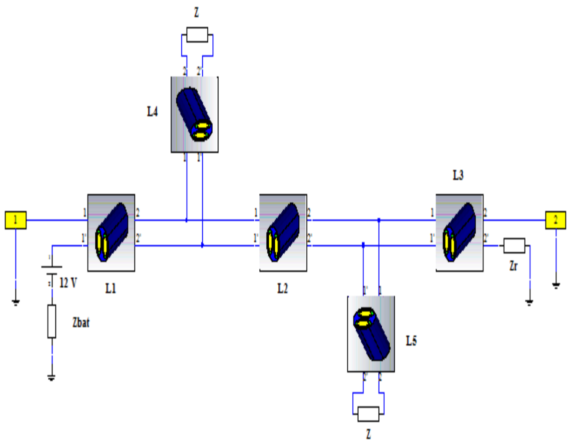

Fig. 6. Section of the vehicle electrical network modelled under CST MW

III. SIMULATION RESULTS AND DISCUSSION

In this section, we compare the simulation results with experimental measurements. The different simulations were obtained by the CST MWS software.

To calculate the S-parameters of the cable under CST MWS, we used the Time Domain solver. The mesh refinement of the structure is automatically done by the software, in order to achieve an accuracy of 1% on the obtained results. The simulated CST-model segment is shown in Fig. 6.

In 3D model, we consider the non-dispersive sheath material. Also, in this model, the skin effect is taken into account.

To validate this modelling method, we proceeded to a comparison between the simulation results and experimental measurements made on a model representing the automotive PLC used in the industry, for more information see [5]. We study the transfer function between E and S for two configurations P1 and P2 (Fig. 6):

- Configuration Open Circuit (OC): no devices are connected in the P1 and P2.
- Configuration Closed Circuit (CC): identical devices are connected to P1 and P2. To simulate this, the impedance matches the electrical and electronic equipment such as lamps, motors, sensors, etc... Measurements made by the manufacturers or suppliers show that the values of impedances can vary from 1 Ω to 1KΩ on a frequency band up to 70 MHz. Four impedance values were considered: Z = 1 Ω, Z = 50 Ω, Z = 120 Ω and Z = 1 KΩ.

The cable length used in this model are (Fig. 6):

L1 = L3 = 0.6 m; L2 = 0.4 m; L4 = L5 = 0.5 m

The comparison between the simulation results and experimental measurements in the band [500 KHz – 70 MHz] is presented in Fig. 7 for OC configuration, Fig. 8 for CC configuration Z = 1 Ω, Fig. 9 for CC configuration Z = 50 Ω, Fig. 10 for CC configuration Z = 120 Ω and Fig. 11 for CC configuration Z = 1KΩ.

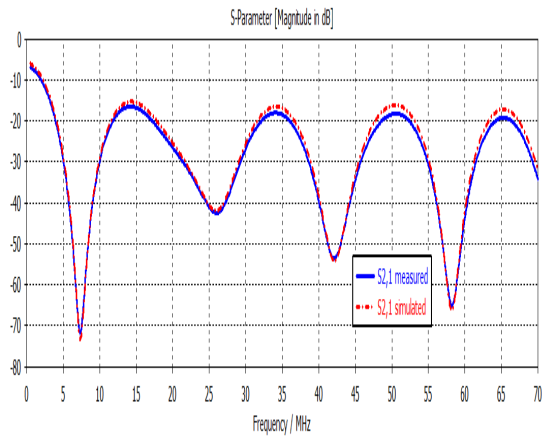

Fig. 7. S21 in OC configuration

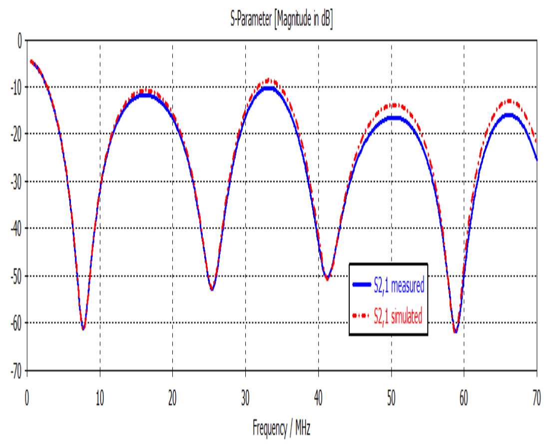

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Fig. 8. S21 in CC configuration (Z = 1 Ω)

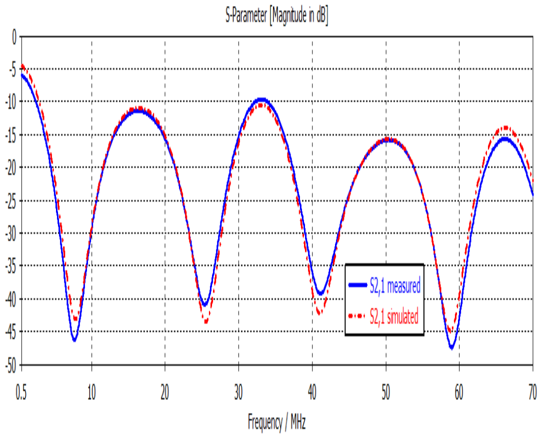

Fig. 9. S21 in CC configuration (Z = 50 Ω)

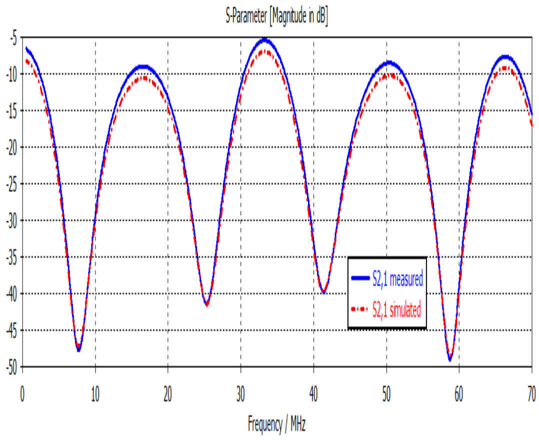

Fig. 10. S21 in CC configuration (Z= 120 Ω)

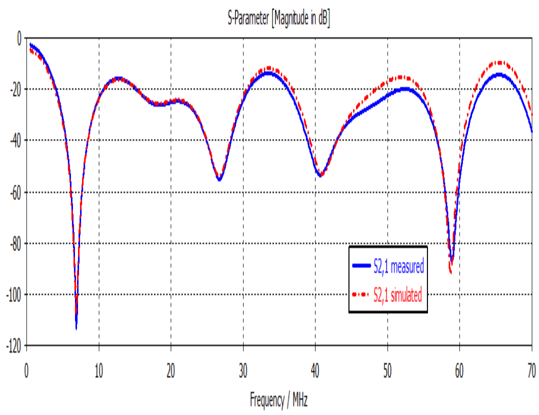

Fig. 11. S21 in CC configuration (Z = 1 KΩ)

For all configurations, we can observe four attenuation peaks: the first at 7.4 MHz, the second at 25.66 MHz, the third at 41.7 MHz and the fourth at 58.48 MHz. This phenomenon is mainly induced by a strong impedance mismatch at P1 and P2. Also, we can see an average difference of 1.5 dB between measurements and simulations. This difference is due to the assumptions made in 3D modelling; assumes that the constant loss angle on the frequency band (non-dispersive sheath material).

In OC configuration, we find that attenuation is maximized (example: -74 dB for the 7.4 MHz frequency). This is caused by the connection of the derivation in open circuit. This derivation acts as a band-stop filter. It behaves like a short circuit at the connection points to the fading frequencies and reflects the incident wave towards the source. Moreover, the measurement confirms the simulation. In addition, it can be noted that the connection of an impedance (CC configuration) improves the frequency response (Fig. 8, Fig. 9 and Fig. 10).

finally, the small difference between measurements and simulations validates the CST-model in the band [500 kHz – 70 MHz].

In this paper, the PLC channel in the in-vehicle scenario has been discussed. A difference of 1 dB ± 0.5 (97% confidence) is obtained between the measured and the simulated. Therefore, this model under CST MWS software reproduces approximately the same frequency behavior of the vehicle PLC channel.

In order to generalize the proposed model, this study needs to be extended to a more complex vehicle network.

Later, this model will be implemented in a software communication tool designed to optimize channel coding and modulation schemes.

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